WIDE BANDGAP TRANSISTORS WITH GATE-SOURCE FIELD PLATES

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to transistors and particularly to transistors utilizing field plates to improve performance.

[0003] 2. Description of the Related Art

[0004] Improvements in the manufacturing of AlGaN/GaN semiconductor materials have helped advance the development of AlGaN/GaN transistors, such as high electron mobility transistors (HEMTs) for high frequency, high temperature and high power applications. AlGaN/GaN has large bandgaps, high peak and saturation electron velocity values [B. Gelmont, K. Kim and M. Shur, *Monte Carlo Simulation of Electron Transport in Gallium Nitride*, J. Appl. Phys. 74, (1993), pp. 1818-1821]. AlGaN/GaN HEMTs can also have 2DEG sheet densities in excess of 10^{13} cm^{-2} and relatively high electron mobility (up to 2019 cm^2/Vs) [R. Gaska, et al., *Electron Transport in AlGaN—GaN Heterostructures Grown on 6H—SiC. Substrates*, Appl. Phys. Lett. 72, (1998) , pp. 707-7099 . These characteristics allow AlGaN/GaN HEMTs to provide very high voltage and high power operation at RF, microwave and millimeter wave frequencies.

[0005] AlGaN/GaN HEMTs have been grown on sapphire substrates and have shown a power density of 4.6 W/mm and a total power of 7.6 W [Y. F. Wu et al., *GaN-Based FETs for Microwave Power Amplification*, IEICE Trans. Electron. E-82-C, (1999). pp. 1895-1905]; More recently, AlGaN/GaN HEMTs grown on SiC have shown a power density of 9.8 W/mm at 8 GHz [Y. F. Wu, et al., *Very-High Power Density AlGaN/GaN HEMTs*, IEEE Trans. Electron. Dev. 48, (2001), pp. 586-590] and a total output power of 22.9 W at 9 GHz [M. Micovic, et al., *AlGaN/GaN Heterojunction Field Effect Transistors Grown by Nitrogen Plasma Assisted Molecular Beam Epitaxy*, IEEE Trans. Electron. Dev. 48, (2001), pp. 591-596].

[0006] U.S. Pat. No. 5,192,987 to Khan et al. discloses GaN/AlGaN based HEMTs grown on a buffer and a substrate. Other AlGaN/GaN HEMTs and field effect transistors (FETs) have been described by Gaska et al., *High-Temperature Performance of AlGaN/GaN HFET's on SiC Substrates*, IEEE Electron Device Letters, 18, (1997), pp. 492-494; and Wu et al. *High Al-content AlGaN/GaN HEMTs With Very High Performance*, IEDM-1999 Digest, pp. 925-927, Washington DC, December 1999. Some of these devices have shown a gain-bandwidth product (f_T) as high as 100 gigahertz (Lu et al., *AlGaN/GaN HEMTs on SiC With Over 100 GHz ft and Low Microwave Noise*, IEEE Transactions on Electron Devices, Vol. 48, No. 3, March 2001, pp. 581-585) and high power densities up to 10 W/mm at X-band (Wu et al., *Bias-dependent Performance of High-Power AlGaN/GaN HEMTs*, IEDM-2001, Washington DC, Dec. 2-6, 2001) and Wu et al., *High Al-Content AlGaN/GaN MODFETs for Ultrahigh Performance*, IEEE Electron Device Letters 19, (1998), pp. 50-53).

[0007] Electron trapping and the resulting difference between DC and RF characteristics have been a limiting factor in the performance of these devices. Silicon nitride (SiN) passivation has been successfully employed to alleviate this trapping problem resulting in high performance devices with power densities over 10 W/mm at 10 Ghz. For example, U.S. Pat. No. 6,586,781, which is incorporated herein by reference in its entirety, discloses methods and structures for reducing the trapping effect in GaN-based transistors. However, due to the high electric fields existing in these structures, charge trapping is still an issue.

[0008] Field plates have been used to enhance the performance of GaN-based HEMTs at microwave frequencies [See S Kamalkar and U. K. Mishra, *Very High Voltage AlGaN/GaN High Electron Mobility Transistors Using a Field Plate Deposited on a Stepped Insulator*, Solid State Electronics 45, (2001), pp. 1645-1662]. These approaches, however, have involved a field plate connected to the gate of the transistor with the field plate on top of the drain side of the channel. This results in reducing the electric field on the gate-to-drain side of the transistor thereby increasing breakdown voltage and reducing the high-field trapping effect. Transistors, however, with gate-drain field plates only have shown relatively poor reliability performance, particularly at class C (or higher class) operation where the electric field on the source side of the gate becomes significant.

SUMMARY OF THE INVENTION

[0009] The present invention provides transistors that operate with reduced electric field on the source side of the gate. One embodiment of a transistor according to the present invention comprises an active region having a channel layer. Source and drain electrodes are in contact with the active region and a gate is between the source and drain electrodes and in contact with the active region. A spacer layer is on at least part of the surface of said active region between the gate and the drain electrode and between the gate and the source electrode. A field plate is on the spacer layer and extends on the spacer and over the active region toward the drain electrode. The field plate also extends on the spacer layer over the active region and toward the source electrode. At least one conductive path electrically connects the field plate to the source electrode or the gate.

[0010] One embodiment of a high electron mobility transistor (HEMT) according to the present invention comprises a buffer layer and barrier layer arranged successively on a substrate, with a two dimensional electron gas (2DEG) channel layer at the heterointerface between the buffer layer and said barrier layer. A source and a drain electrode are included both making contact with the 2DEG, and a gate is included on the barrier layer between the source and drain electrodes. A spacer layer is on at least part of the surface of the barrier layer between the gate and the drain electrode and between the gate and the source electrode. A field plate is on the spacer layer, extending on the spacer over the barrier layer toward the drain electrode and extending on the spacer layer over the barrier layer toward the source electrode. At least one conductive path electrically connects the field plate to the source electrode or the gate.

[0011] One embodiment of a metal semiconductor field effect transistor (MESFET) according to the present invention comprises a buffer layer on a substrate and a channel layer on the buffer layer, with the buffer layer sandwiched between the channel layer and substrate. A source electrode is in electrical contact with the channel layer and a drain